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Standards and policies for very high energy efficiency in the urban building sector towards reaching the 1.5°C target

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Reliably reducing the emissions in the building sector plays a crucial role if the 1.5°C climate target from the Paris Agreement is to be met. The observed trends show a significant increase in building energy use, especially in emerging economies. Counteracting these trends is absolutely essential, especially in the light of urbanisation, population growth and changing lifestyles. In terms of mitigating the climate impact of buildings, ensuring high levels of efficiency (i.e. very low energy needs, especially for heating and cooling) has the greatest potential for saving energy and emissions, and is at the same time the prerequisite for effective use of energy from renewable sources. Clearly defined targets and suitable metrics are essential to enable appropriate design decisions. Implemented projects clearly indicate that quality assured design and construction lead to reliable in-use energy performance. Effective policy packages to address opportunities and challenges are important drivers to support the uptake of state-of-the-art efficiency measures in the urban building sector.

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Introduction

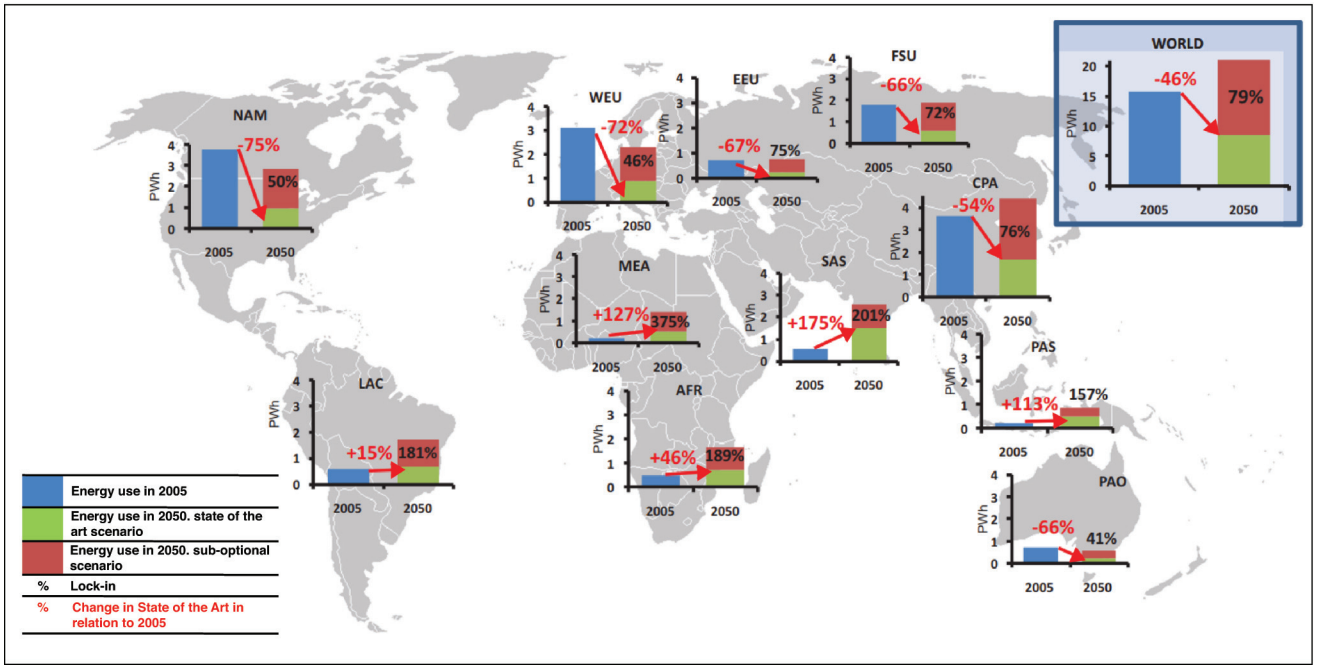
In 2010, 30% of the CO_2 emissions and 32% of the global final energy use originated from the building sector [1]. Out of this, 55% of the total energy use in buildings falls back on thermal energy, including heating, cooling and hot water [2]. Reliably reducing the emissions in the building sector plays a crucial role if the 1.5°C climate targets are to be met, especially since it is recognised as one of the most cost-effective mitigation actions [2,3].

The comprehensive data analysis presented by Ürge-Vorsatz *et al.* [4••] suggests, however, that, assuming business as usual, the global heating and cooling energy use in the residential sector will increase by 80% (2010–2050). Here, urban areas play a crucial role by accounting for 85% of the thermal energy increase in residential buildings, 70% of which can be attributed to cities in developing countries. Figure 1 shows the status quo and predictions for different regions of the world. The numbers stated in literature differ but the tendencies are the same [4••,5]: The highest contributor (residential and commercial sector) is currently North America, followed by buildings in Centrally Planned Asia and Western Europe. Under a business as usual efficiency scenario, the energy use in developed parts of the world is predicted to stay fairly level or even decrease, whilst significant increases are expected in other regions. The highest increase is predicted for South Asia (incl. India), up to fivefold according to [4••]. Centrally Planned Asia (incl. China) is predicted to have the highest energy use in 2050, as the currently already high figures are expected to further increase.

Major influencing factors for the increase in energy use are societal effects such as, for example, urbanisation, population growth with an increase in household numbers and per capita living space, as well as augmented comfort standards and changing lifestyles [4••,5–7]. These effects are counteracting savings achieved through improved efficiency levels [4••], with the consequence that even higher efficiency levels are needed to achieve a substantial change.

Consequential sustainable changes in the building sector will only be achieved by following a deep mitigation pathway, focussing on solutions with very high levels of energy efficiency (EE), that is, significantly reducing the energy need for heating and cooling. Scenarios show that state-of-the-art approaches focussing on high EE for refurbishment and new build could result in worldwide overall energy savings of 46% in 2050 compared to

Figure 1



Energy use for heating and cooling in different regions of the world, according to the Global Energy Assessment [8]. The data compare the energy use of 2005 with two predictions for 2050 based on suboptimal developments versus application of state of the art technologies. Employing state of the art technologies indicates a reduction potential in energy use of 46% compared to 2005 figures; 79% savings compared with a suboptimal development ('lock-in').

2005 — despite increasing amenities, comfort and floor area [5,8]. The 1.5°C climate target can only be achieved if decarbonisation of the energy supply are coupled with such extensive reductions of the energy demand, so that the limited amount of available zero-carbon energy sources can cover the resulting global energy demand.

Against this background, this paper aims to provide an up-to-date review of the recent literature on the evidence for proven and reliable highly energy efficient buildings, also in the urban context. It discusses success factors for reaching global warming targets, and evidence of policies and measures that are likely to harness the potential.

An overview: high-efficiency building standards

Numerous voluntary building standards exist that promote energy efficient buildings. This section provides an overview of different types and how they each address the topic of energy performance. For an indicative comparative overview Table 1 summarises selected voluntary standards with a focus on energy performance rating. Some studies exist that qualitatively compare the energy rating of different building standards, for example, [9–11] but further research on this subject is needed to advance the discussion and provide clarity on how standards compare, especially with regard to the relevant outcome, that is, the measured energy performance of buildings.

Green Building Rating Systems (GBRS)

GBRS typically incorporate various environmental categories, for example, energy, water, materials, location, indoor environmental quality [9,19]. Energy rating plays a dominant role in most GBRS [19,20] and it is becoming an increasingly dominant feature with updates to the respective standards. This trend confirms recognition of prioritising energy aspects amongst the various environmental categories. Literature review indicates, however, that the achieved energy efficiency level of accredited GBRS buildings varies and that a high overall rating do not necessary imply high energy efficiency levels [21–23]. One explanation for this effect is that most GBRS are based on an accumulative credit system that allows trade-offs between energy efficiency measures and other environmental categories to a certain extent [23,24], so that a high rating can also be achieved without a focus on reducing the energy needs. Furthermore, the energy performance is predominantly rated based on relative percentage savings with respect to a baseline building [25]. With assessments based on diverging baselines, calculation tools and indicators (e.g. primary energy, CO_2, energy costs) the expected energy performance of

Table 1

Qualitative comparison of how selected voluntary building standards assess energy performance

Type	Environmental Standards/Green Building Rating Systems				Energy Standards		
Name	BREEAM [12]	LEED [13]	CASBEE [14]	Green Star [15]	Zero Energy Certification [16]	Minergie® [17]	Passive House [18]
Organisation; Country of origin; Region of application	UK Building Research Establishment	USA U.S. Green Building Council	Japan Japan Sustainable Building Consortium	Australia Green Building Council of Australia	USA International Living Future Institute & New Building Institute	Switzerland Verein Minergie	Germany Passive House Institute
Main application	International	International	Japan and Asia	Australia	US and Canada	only Switzerland	International
Main assessment categories	Energy/Health and Wellbeing/ Innovation/Land use/ Materials/ Management/ Pollution/Transport/ Waste Water	Location and Transport/ Sustainable Sites/Water Efficiency/Energy and Atmosphere/Material and Resources/Indoor Air Quality/Innovation/ Regional Priority	Indoor Environment/ Quality of Service/ Outdoor Environmental (On-Site)/Energy/ Resources & Materials/Off-Site Environment	Management/Indoor Environment Quality/ Energy/Transport/ Water/Materials/ Land Use & Ecology/ Emissions/Innovation	Energy	Energy + Health & Materials optional add-on	Energy Indoor Air Quality/ Thermal Comfort
Scoring system	Weighted credits Minimum requirements in some categories	Weighted credits Minimum requirements in some categories	Weighted credits No minimum requirements	Weighted credits Minimum requirements in some categories	Pass or fail based on threshold value	Pass or fail based on threshold values	Pass or fail based on threshold values
Tiers	Pass/Good/Very Good/Excellent/ Outstanding	Certified/Silver/Gold/ Platinum	C: Poor/B−: Fairly poor/B+: Good/A: Very good/S: Excellent	Zero to Six Stars	–	Minergie/Minergie-P/ Minergie-A + add-on 'ECO'	Classic/Plus/ Premium
Energy performance rating method	Relative savings Baseline building: Regulations of respective country	Relative savings Baseline building: App G, ASHRAE 90.1	Relative savings Baseline building: Energy Conservation Law 2013	Relative savings Baseline building: Construction Code Section J	Performance requirements Assessment method based on monitored data; no planning guidelines how to achieve these targets	Combination of relative savings and performance requirements Baseline building: MuKEn 2014	Performance requirements
Main energy performance indicator	Useful energy, primary energy and CO_2 emissions	Annual energy operational costs	Annual thermal load and primary energy	Greenhouse gas emissions and peak electricity demand	Metered energy	Useful energy (heating) and primary energy (2 targets for different energy services)	Useful energy (heating, cooling) and primary energy (all energy services)

highly rated buildings from different GBRS is not coherent.

Consequently, even though GBRS include suitable approaches for improving efficiency levels, they cannot be considered a reliable pathway for reducing the energy needs of the building sector in accordance with climate targets.

Energy performance standards

A common theme in literature when it comes to standards for highly energy efficient buildings is the concept of 'zero energy buildings' (ZEB). ZEBs use a combination of energy conservation, efficiency measures and renewable energy generation [26] to achieve an offset of energy needs with renewable energy supply. Despite the seemingly simple concept there is a lack of a common understanding for a clear definition [27–32]. Marszal *et al.* [29] provide an informative overview of different ZEB definitions. Even though it is widely agreed in literature that a building's energy needs should first be significantly reduced through efficiency measures and only then renewable energy sources be used to cover the remaining energy needs [33], ZEB definitions do not typically include a requirement for the energy performance with the consequence that moderate efficiency levels can be compensated for with increased production of RE [29,30,34].

ZEB concepts are being increasingly adopted and the acceptance is reflected in the integration in energy codes and policy. Wells *et al.* [32] mention the U.S., Canada, Japan and EU member states as the most advanced countries in this regard. In Europe, the Energy Performance of Buildings Directive (EPBD) [35] provides a binding legal framework for all European member states to align their national regulations to require so-called nearly zero-energy buildings (nZEB) by the end of 2020. The EPBD, however, also leaves room for interpretation by member states and a comparison of nationally implemented codes clearly shows that approaches vary significantly in terms of definitions and resulting energy performance [36,37].

Clear numeric energy targets that cannot be compensated by other measures are a key for achieving high performance. Passive House (PH) and Minergie are two such performance-based standards. They differ in terms of precise definition and a direct comparison is more complex than one might expect. Firstly, the energy services included in the targets vary and secondly, the reference floor is defined differently (e.g. gross area for Minergie, which is typically 30% higher than living area used for Passive House). Consequently, it is not always the case that lower numeric targets (more ambitious at first glance) in fact lead to buildings with lower energy needs.

The Passive House Standard is currently the only standard that consistently prescribes efficiency levels of the building envelope via clear targets for the energy needs for heating and cooling. Overall, to the best of the authors' knowledge, the Passive House criteria sets the most ambitious requirements. PH effectively minimises heating and cooling loads most amongst all standards, and can thus be considered an unmatched concept for achieving the ambitious climate targets. It should be considered as a pathway and baseline approach, which can of course be supplemented with wider sustainability aspects. A confirmation of this correlation is the recent recognition of Passive House accreditation for automatically meeting the energy requirements of the Australian Green Star standard [38].

To provide a better understanding: Passive House being a performance-based standard, it is about optimising a building's design and properties in the context of the local climate conditions [39–41]. It is a design process with suitable tools that enables the identification of optimal components and has led to numerous successful projects worldwide [42•]. The energy targets were originally derived based on the underlying concept of cost-effectiveness, where potentially increased investments in higher efficiency are offset by lower or fully eliminated investments in heating/cooling systems and marginal energy costs [8,39]. Schnieders *et al.* [41] present the results of a comprehensive study, which provides an overview of the typically required building components qualities worldwide. Example studies in recent literature that review the application for new-build and retrofit projects under varying climate conditions include [43–50]. Highly relevant in the context of areas with highest potential for an impact on climate change mitigation is the recent uptake of Passive House projects in China, including promising monitoring results [51].

Success factors for reaching global warming targets

Interplay of energy efficiency and renewable energies

The general prioritisation in order to achieve climate targets is: Firstly, sufficiency (changing quantity or quality of energy services while still providing everyone's basic needs to a sufficient level); secondly, efficiency (reducing the energy need to provide services) and finally, sustainable, renewable energy supply [52]. In order to successfully decarbonise the building sector, efficiency measures and renewable energy (RE) supply must come hand in hand. The system must be viewed and optimised as a whole [33,53]. Taking into account resource limitations (especially space), a substantial reduction in energy needs is a prerequisite to enable extensive RE coverage [54,55]. In order to successfully reach global warming targets, high efficiency for buildings should therefore be tackled first [56].

A vital aspect to be considered is the interplay of renewable energy generation and the energy load of buildings in terms of both 'load matching' and 'grid interaction' [57]. Conventional approaches to assess the environmental impact of a buildings energy use are typically based on primary energy or emissions of units of CO_2-equivalent. Establishing alternative indicators in the light of increasing renewable energy supply is an ongoing research topic represented in recent literature. Readjusting the current assessment metrics is required to help prioritise measures that result in the largest environmental benefits [26,57–61,62•].

Salom *et al.* [57] provide a comprehensive review and comparison of a number of different load match and grid interaction indicators applied to case studies, most prominently the 'load cover factor' and 'supply cover factor'. Cao *et al.* [58] define extended load match indices for increasingly complex on-site energy systems. Cubi *et al.* [59] propose a method to incorporate the intensity variations of GHG emissions over the course of the year into the environmental performance assessment of buildings via 'Carbon Emissions Factor' (CEF) that vary for different points in time. Similarly, the 'Grid Compensation Score' [60] provides a quantitative indicator for the contribution of a building's energy load on mitigating variability in the electricity grid.

These approaches clearly demonstrate that the energy needs of buildings and the supply structure of the grid are closely interlinked. The recommendations of environmentally sustainable solutions thus depend on evolving grid composition and dynamics — suggesting that environmental indicators might need to be adjusted with time. As a novel approach to break down these complex correlations Feist [54,55] proposes the assessment method based on 'Primary Energy Renewable' (PER), which anticipates the grid developments towards an envisaged scenario of 100% renewable energy supply. On the basis of the analysis of worldwide building simulations, PER weighting factors have been determined that can be applied to a building's annual energy needs [61]. These factors vary between approx. 1 and 2.5 for different locations, different energy carriers and different energy services (heating, cooling, hot water, electricity), which reflects the temporal correlation between need and supply, as well as regional renewable resource availability [54,62•]. A factor of 1.6 for the electricity use for heating, for example, means that 60% more renewable electricity must be supplied than is needed at the building to compensate for short term and seasonal storage losses.

This means that, despite the recent and expected reductions in costs of, for example, solar PV electricity, high EE may still be more cost-effective taking into account these PER weighting factors as well as the overall energy system costs of integrating electricity from fluctuating renewable energy sources. A simulation study by Copiello [63] showed that currently still the cost optimum is close to high energy efficiency building concepts but not with self-sufficient houses (see Figure 2) [64].

Reliable performance of highly energy efficient buildings

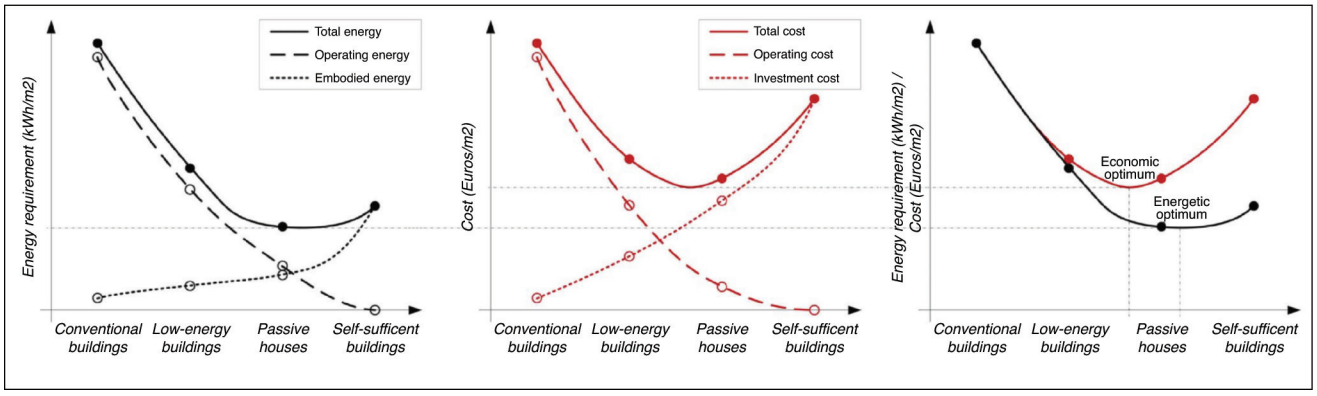
Reliable energy performance and elimination of a significant 'performance gap' are crucial if climate targets are to be met. Sufficient examples exist to prove that savings can reliably be achieved in reality (see below). However, it cannot necessarily be taken for granted that buildings will perform exactly as intended. It is important to differentiate between discrepancies due to failure or due to occupant behaviour [65]. To reduce the risk of failure, quality assurance and transparency are vital, most importantly during the planning stages [66] but also during construction, system commissioning [67] and — especially for more complex buildings — during operation. To this end, suitable calculation and design tools are needed [68], as well as reliable EE components [69] and sufficient expertise [70].

With appropriate quality assurance measures in place reliable long-term performance can be secured. Johnston and Siddall [71•] report on the *in situ* performance specifically of the building fabric, tested by means of co-heating tests. The results demonstrate that the case studies with highest EE perform best (Passive House buildings versus low energy buildings). One of the main reasons specifically pointed out are the quality assurance methods of a consistent design and detailing process, as well as the close site supervision and careful workmanship.

The first extensive and statistically significant monitoring of highly energy efficient buildings to the Passive House efficiency level in several European countries was published in 2001 [72,73]. The expectation for stability of performance of efficiency measures in the long term is supported by measured data presented in Feist *et al.* [74]: The energy use of this pilot project has remained stable for over 25 years. A rigorous examination of individual components (e.g. insulation material, mechanical ventilation system, airtight layer, window performance) showed no signs of ageing that might jeopardise the future energy performance.

High EE solutions have also proven themselves on a larger district scale in the urban setting. Rojas *et al.* [75], for example, provide an extensive report on the performance of multifamily apartment blocks in Innsbruck, Austria. In addition to an analysis on the energy performance, this study also highlights the comfort and quality that can be achieved in these buildings. Peper [76] present the monitored performance data of an even larger scale project with >1000 apartments in 8 different multifamily blocks in Heidelberg, Germany. The

Figure 2



Indicative economic and energetic optimum ranges (right) under consideration of trade-offs between operating and embodied energy (left) or between operating and investment costs (middle).
Source: Copiello [63].

measured average energy need for heating is as low as 15.7 kWh/(m^2 a) and in very good agreement with calculated predictions.

User behaviour adds an uncertainty to the energy performance of any individual building. Examples in recent literature report on differences in prediction and performance, mainly ascribed to the usage pattern of the building and the occupants' behaviour [65,77]. Only the analysis of statistically significant numbers of identical dwellings with diverse user behaviour can prove whether the average performance was successfully predicted or whether there is indeed a systematic 'performance gap'. Feist *et al.* [42•,73] present several statistically relevant case studies of Passive Houses and low energy buildings where the calculated energy demand is in good agreement with the average performance (see Figure 3). The calculation tool used for the purpose of making design choices must be suitable for reliably predicting the average performance [68].

With respect to the user influence, Pitts [70] notably points out that " . . . occupants have relatively less impact on building performance in very low energy design than other types". Statistical analysis proves that the differences in absolute energy consumption caused by user influence in highly efficient buildings is significantly smaller and becomes almost negligible in comparison to the achieved savings of effective EE measures [42•].

Challenges and opportunities in the urban context

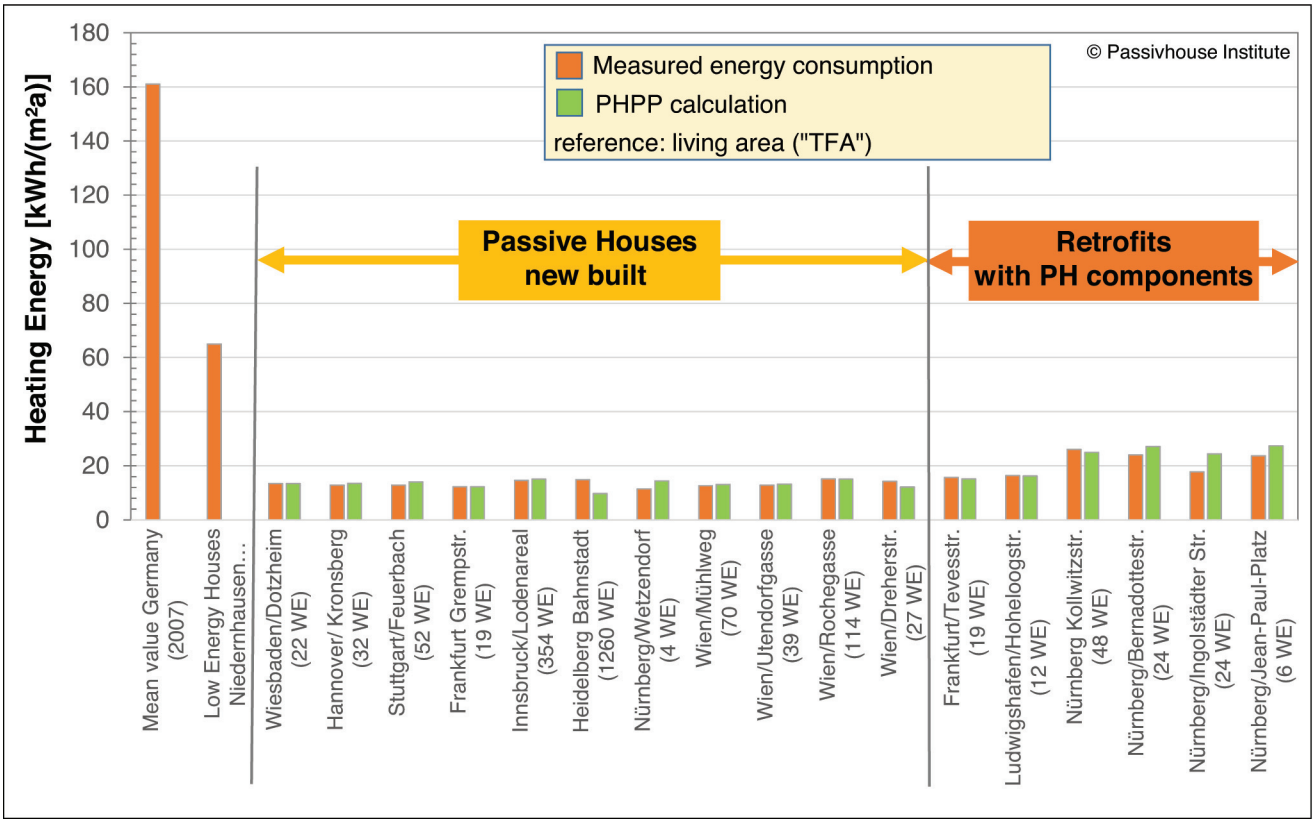
The urban context is complex and diverse due to buildings of different types and ages, various constraints and special boundary conditions, for example, urban heat island effects. The typically higher density poses challenges but also raises opportunities. High-density is typically found to be the more sustainable living model, especially when taking into account related aspects of urban planning and urban form [79•,80].

The majority of buildings in a dense setting are of a compact shape, which is very advantageous for high EE, as less insulating effort is required to optimise the building fabric. In their research about the impact of urban density on per capita energy use in cities, Resch *et al.* [80] highlight the positive impact of tall buildings, especially in colder climates. In recent years, the uptake of Passive House has also shown a trend towards highly energy efficient high-rise projects [81–83].

One challenge of the urban setting can be constraining boundary conditions, for example, shading from neighbouring buildings or a given orientation. Reduced amounts of passive solar heat gains may need to be compensated for with other measures (e.g. more insulation). Despite these challenges, implemented examples show that very high efficiency levels can still be reached (e.g. the above-mentioned example district in Heidelberg, Germany [76]).

Multi-storey buildings, as often found in urban settings, have a smaller available roof space for renewable energy supply relative to their floor area. They are thus systematically at a disadvantage with respect to ZEB targets, even if they meet very high efficiency levels. Rating the energy efficiency and energy production for a specific object independently of one another prevents misleading design choices and encourages optimisation of both aspects. One possibility is to use the building's footprint as reference for the renewable energy supply [62•] and to take into account off-site production, as also considered in the EPBD [35]. Balancing energy need and renewable supply should be considered on a district or even regional

Figure 3



Feist *et al.* [42•] present statistically significant data from very high energy efficient buildings that confirm reliable performance for space heating, in agreement with calculated predictions (PHPP = Passive House Planning Package [78]).

level. Urban density provides a significant potential for cost-effective and efficient low emission district energy supply systems, which makes EE an especially attractive strategy for cities [79•].

While the focus of this paper is mainly on high EE solutions at the level of individual buildings, it is important to also look beyond the individual building and address the urban scale. This is because, as Soares *et al.* [79•] put it: "urban design is directly and inherently linked to the environmental performance of an individual building, as it is often determinant for its typology and orientation, for example". There are also more indirect linkages between urban structure and the energy use associated with buildings, such as, for example, impacts on urban microclimate or on transportation demand [79•]. Energy-sensitive urban planning that carefully balances positive and negative impacts of urban densification on energy use is therefore a prerequisite for achieving sustainable low-carbon cities [84].

Existing building stock

In most developed countries, new construction only accounts for 1–1.5% of total building stock, whilst the vast majority consists of existing buildings [85]. This diverse existing building stock in cities contributes a significant share to the total energy use and according to the European Commission [86], provides the largest cost-effective energy saving potential. Tapping into this potential through suitable retrofit practices is vital with regard to preventing long-term energy lock-in [87]. Upgrading the building stock to highest efficiency is crucial in order to enable a decarbonised energy supply [88]. According to the European Parliament deep renovation refers to a reduction by at least 80% (both delivered and final energy) compared with the prerenovation levels [89]. Despite the challenges and constraints, projects exist to show that such deep retrofits leading to very high efficiency levels with an very low heating energy of 25 kWh/(m^2 a) or below can be achieved [90]. The market uptake, however, of such deep renovations remains low and measures to increase retrofit rates and retrofit depth need to be emphasized [91•,92]. The dissemination of available solutions and guidelines for decision processes, as presented, for example, by Bastian *et al.* [93], is of high importance to support uptake. For economic viability it is important that every retrofit cycle — whole buildings or individual components — is coupled with best practice

improvement of the level of energy efficiency, so that energy cost savings only need to cover the additional EE investment costs [94]. This is especially important for phased retrofits [92,95,96]. Setting up a roadmap of individual steps towards the final energy efficiency target is invaluable in terms of identifying retrofit synergies avoiding missed opportunities and energy lock-in. Examples of support tools to develop such include the EnerPHit Retrofit Plan [96] or the roadmap guidance provided by the German Federal Ministry for Economic Affairs and Energy [97].

Policies

There is a long history of research on the so-called energy efficiency gap, that is, the existence of energy efficiency improvement options that are both technically feasible and economically viable but are not taken up by end-users. This is due to a variety of barriers and market failures, such as, for example, externalities, information failures, high up-front costs, and split incentives [98–100].

On the other hand, recent research has put much focus on the multiple benefits of energy efficiency [101–104]. These are especially relevant in the building sector, as highly efficient buildings offer significant additional advantages beyond the savings in energy, cost and CO_2 emissions that mostly form the primary (political) rationale for improving building EE. Additional benefits occur in many areas, such as health and well-being, social welfare, employment, macro economy, air pollution, resources and energy system [103•,105].

To overcome the barriers and make use of the multiple benefits of highly energy-efficient buildings, strong policy support for these is needed. Recent research showed that without more ambitious policies in the building sector, more than 80% of the economically viable potential would remain unrealised by 2035 [101] and that continuing the current 'moderate efficiency' pathway with existing policies would still lead to almost 50% increase of total final building thermal energy use by 2050 as compared to 2005. This also means that 80% of 2005 demand levels would be locked in until 2050, thus seriously jeopardising the agreed climate targets [52].

To address the various barriers and target groups in the building sector, a policy package, that is, a targeted combination of different types of policies is needed. This typically includes (1) regulation, most importantly minimum energy performance standards (MEPS) for whole buildings and their technologies/components; (2) information and motivation, especially through building energy labelling, and individual advice; (3) economic incentives and financing support to address, for example, capital constraints and risk aversion; (4) education, training, and quality assurance; (5) urban or district planning instruments for ensuring an energy-efficient energy supply; as well as (6) measures to stimulate development and diffusion of very high efficiency solutions (e.g. research and development and demonstration) ([106] advancing findings from [107–109]). While (1) ensures that the least efficient building technologies and performances are banned from the market, (2)–(4) stimulate market uptake of high efficiency technologies and building concepts [109]. These sector-specific policies also need a framework for general EE governance. This includes both sectoral targets and policy roadmaps; energy agencies, energy efficiency funds, or energy efficiency obligations for energy companies; as well as energy/GHG taxation, emissions trading, and/or removal of energy subsidies [106].

Policies to advance high EE standards in buildings and more widely in the urban renewable energy supply context are thus an important element to any climate policy aiming at achievement of the 1.5°C climate target. This follows from the facts that high energy efficiency in buildings is indispensable for meeting the 1.5°C target [2,3,8], and from the barriers to high energy efficiency in buildings mentioned above. General climate policies, such as energy/GHG taxation and emissions trading are also necessary elements of the policy package for high energy efficiency in buildings as discussed above, but they are not sufficient, due to the barriers [109].

Especially when looking at the 1.5°C target of the Paris Agreement, scenario analysis by Kranzl *et al.* [91•] shows that an almost completely decarbonised building stock will be needed by 2050 and that this goal will not be achieved with current measures or even with assumed 'ambitious policy scenarios' in different modelling projects. Significant upscaling of policy action is therefore required within a very short timeframe, for example in Europe, to increase average savings in refurbishment to 70% while achieving renovation rates of 2.5% per year, combined with the phase-out of fossil fuel based heating systems within the next 10–15 years [91•]. Policymakers also need to consider making energy retrofits of inefficient buildings mandatory, as France did in its 2015 energy transition law: all residential buildings with a primary energy consumption above 330 kWh/m^2 per year must be energetically renovated before 2025 [110,111]. In emerging economies, the focus should first be on introducing and/or (gradually) tightening building energy codes towards very high efficiency buildings as fast as possible [109].

The urgency to address building related energy use and CO_2 emissions more stringently becomes even more evident in light of the fact that global floor additions of 230 billion square meters are expected until 2060, mainly in Asia and Africa (more than two thirds of total floor additions). Half of this growth is predicted to take place within the next 20 years, which is why action needs to be taken now, especially in developing countries, where the

largest floor additions will occur and are often currently not (yet) covered by mandatory building energy codes [112].

For ZEB policies, success factors include stakeholder involvement in policy design and implementation, stable, long-term targets, and regularly updated policies to account for technology and market evolution [107], as well as combining policies to increase cost-effectiveness (e.g. advice programmes as catalysers for economic incentive policies) and international transfer of policy design and implementation tools to reduce implementation costs [113]. Compliance control and enforcement as well as monitoring of regulatory policies are also very important to ensure reliable savings. With regard to making ZEB the standard, it may furthermore be beneficial to better align policies aimed at reducing building energy needs with those promoting renewable (specifically solar) energy, especially in developing countries [33]. Knowledge transfer and capacity building for professionals along the whole building sector supply chain as well as the formation/strengthening of actor networks is key to increase uptake of high EE buildings and also to ensure reliable performance of buildings, for example in India [114].

Conclusions

With appropriate policies and building design standards focused on reliably achieving very low energy needs for heating and cooling, such as the Passive House concept, the building sector can contribute its share to the 1.5°C goal, both for new-build and refurbishment of the existing building stock. In this regard, preventing energy lock-in is decisive. Effective policy packages to address all market sectors and barriers are important drivers for an accelerated uptake of state-of-the-art efficiency measures.

The technologies, the expertise, design tools and appropriate quality assurance processes are available to ensure reliable performance and effective energy savings of 70–90%. This has been proven by a statistically significant number of monitoring projects. Such significant reductions in energy needs are key to enabling an extensive coverage from renewable resources, thus creating an overall sustainable energy supply of the buildings stock in line with climate targets. Suitable assessment systems, which include both an index of 'energy needs for heating and cooling' and an appropriate evaluation of interplay with renewable energies, provide opportunities to optimise both the efficiency and sustainable energy supply.

In addition to savings of energy, emissions and costs, the resulting buildings provide multiple other benefits, such as for social welfare (comfort and health), employment, macro economy, air pollution, resources, energy systems and resilience to climate change. Municipalities benefit from these synergies if they choose to facilitate energy efficiency and the use of renewable energy resources of their regions, thus accelerating the transition to a decarbonised future. National and municipal policies to advance high energy efficiency in buildings and more widely in the urban renewable energy supply context are an important element to any climate policy aiming at achievement of the 1.5°C target.

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- • of special interest
- •• of outstanding interest

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